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Ship Service Life and Naval Force Structure

ABSTRACT

The Naval Sea Systems Command has conducted several interdisciplinary studies recently, motivated by a need to address the high cost and extended duration of naval vessel design and construction. Naval architecture and force structure studies have been key components of these efforts. Two general approaches are available: development of alternative future fleet design and programming concepts, and changes in ship expected service life policy. These are not mutually exclusive alternatives; service life is a key variable in future force planning regardless of any other variables considered. In this paper, issues associated with both approaches are described and discussed. Potential implications for future naval force structure planning are identified and recommendations for future work are suggested.

INTRODUCTION

Specifying the U.S. Navy's future composition or "force structure" and building a shipbuilding plan that supports a realistic expectation of achieving and maintaining it, has been a high-visibility problem in recent years due to the "spiraling cost growth in naval vessels" (U.S. Congress 2005). The Navy's current shipbuilding plan for the 313-ship fleet has been described as unrealistic ("pure fantasy") in Congress (Taylor 2008), and U.S. government agencies such as the Government Accountability Office (GAO), Congressional Budget Office (CBO) and the Congressional Research Service (CRS) have presented alternative analyses that point out challenges that will need to be overcome to realize the planned force structure (GAO 2005, Labs 2006).

On the 30 year shipbuilding plan submitted by the Navy in 2006, GAO found that "...there is

tension inherent among the plan's multiple objectives. For example, demanding mission requirements can result in more costly ships that cannot be built in the numbers desired for presence and shipyard workload. These tensions presage the potential trade-offs that will likely have to be made. The key is to anticipate and make trade-offs early in the context of the overall shipbuilding strategy" (Francis 2006). In the course of recent in-house work that addresses this need for early trade-offs, the Naval Sea Systems Command Future Concepts and Surface Ship Design Group has developed an approach for conceiving and evaluating alternative concepts for the future composition of the U.S. Navy over the coming three decades. The approach is interdisciplinary and requires ship concept design work, the formulation of build plans, cost estimating, and warfighting assessments. In other words, fleet synthesis and analysis.

Fleet synthesis and analysis involves constructing alternative views of the future, then setting up and tracking the resulting course of evolution from the present fleet to a long-run future state. The process of evolution is a key factor in distinguishing different alternative future plans, and ship service life one of the principal evolutionary mechanisms. Relatively small changes in service life projections or assumptions have direct and large impacts on future force structures. The result is that the courses of action available to Navy planners can be sorted under two top-level headings:

- (1) Alternative concepts for future force structures, ship designs, and acquisition strategies, and
- (2) Alternative projections of ship service life.

To elaborate these, three topics are addressed in this paper: (1) synthesis and analysis of future naval fleets, (2) views of service life,

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| 14. ABSTRACT The Naval Sea Systems Command has conducted several interdisciplinary studies recently, motivated by a need to address the high cost and extended duration of naval vessel design and construction. Naval architecture and force structure studies have been key components of these efforts. Two general approaches are available development of alternative future fleet design and programming concepts, and changes in ship expected service life policy. These are not mutually exclusive alternatives; service life is a key variable in future force planning regardless of any other variables considered. In this paper, issues associated with both approaches are described and discussed. Potential implications for future naval force structure planning are identified and recommendations for future work are suggested. | | | | |
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and (3) service life impact on force structure and elements that impact actual ship service life.

LITERATURE REVIEW SUMMARY

Naval force structure is a high-impact topic not only for the U.S. Navy but for the national economy and American society as a whole; analyses and views appear from time to time in the *Naval Institute Proceedings*, the *Naval War College Review*, public policy journals, and elsewhere. Government offices and government-funded non-profit research centers have published studies in recent years as well, some in response to Congressional mandates.

There are several general approaches to naval force structure studies. The most radical approach is to propose a new theme or set of themes for future ship ideas, then re-formulate the Navy's ship acquisition programs according to those themes. The Office of Force Transformation (OFT) did a considerable amount of work in this manner in the early- to mid-2000s (Johnson and Cebrowski 2005, Holzer 2005). Themes included "information has been substituted for mass" and "power and survivability of a fleet have been decoupled from size." This speculative approach can stimulate thinking and R&D planning and is therefore a necessary function in any technologically-impacted organization that makes plans 30 years into the future. However, if the themes are too radical or require too many drastic alterations to programs of record (OFT introduced non-nuclear submarines), then their direct and immediate influence can be less than their high public profile would suggest.

From the shipbuilding stability standpoint, a study situated at the opposite end of the spectrum would be one that proposes no changes in ship designs or acquisition programs. Here, study variables concentrate on non-naval architectural parameters, for instance military strategy and presence. This encourages a focus on maintenance cycles, deployment lengths, crewing strategies, and

so on. An example of this kind of study is Gilmore (2005). Studies lying in between the two extremes include those done by Greer, et al (2005) at the Institute for Defense Analyses, and Work (2005) at CSBA.

Many force structure studies in the literature, including those cited above, do not focus on the process of evolution from the present reality to the postulated future. They compare today's situation to a future "end state" where the fleet is a pure embodiment of the new force structure idea without residual ships left over from past planning. Intermediate stages of evolution, with mixed fleets, are not evaluated and the time required to achieve the end state fleet is not estimated. This is a distinctly limited view. Ships are long-lived assets purchased in small numbers and these two facts combine to produce considerable force structure inertia.

Labs (2003) studied transformation in the surface combatant sector of the force structure and he did consider the period of evolution from the present fleet to the future fleet. He concluded that the direction the Navy's force architecture takes after 2025 "will be determined largely by what the Navy decides to do with its Arleigh Burke class destroyers." He mentions that "historically, surface combatants become less effective in wartime operational environments well before the end of their notional 35-year service lives in the absence of midlife improvements to their combat systems."

SYNTHESIS AND ANALYSIS OF FUTURE NAVAL FLEETS

Our approach for developing and evaluating alternative future fleets is shown in Fig. 1. This method was originated and developed in an interdisciplinary environment in NAVSEA during 2006 (Koenig et al 2008). There are seven steps:

Step 1: Define the baseline fleet architecture. That is, define the Navy's existing plan for shipbuilding. This is defined in terms of tactical groups, warfare system counts, and presence. Future naval capabilities are gauged by tactical groups (carrier strike

group, expeditionary strike group). This allows individual ship designs to vary within a design trade space, without having to make changes in military doctrine.

Step 2: Generate group options. Conceive options for new ship classes within the major type-groups such as surface combatants, amphibious assault ships, combat logistics vessels, and so forth. Do rough, parametric designs and initial subjective assessments of their attractiveness in terms of the relevant criteria. These would include cost, mission capability, operational flexibility, adaptability, commonality, ability to transition beyond the program of record, and specific criteria as needed within each group.

Step 3: Assemble alternative fleets. By selecting from the ship design options in Step 2, assemble new alternative fleets. These fleets can be assembled based on a criterion such as SCN cost, by a design theme such as “fewest designs” or “most use of common machinery” or others.

Step 4: Establish technical and program characteristics of the alternative fleets. Create ship concept designs (that is, pre-program ship designs) for each ship design

option that appears in one or more of the alternative fleets. Assemble the ship concept designs into working ship construction “build plans;” this requires juggling fleet need dates, estimated acquisition lead times, service lives, and industrial base loading considerations. The result is a working shipbuilding plan reflecting annual ship acquisitions and retirements by class.

Steps 5 and 6: Ship acquisition cost estimates and sufficiency analysis. For our analyses, ship acquisition cost estimates are performed by the NAVSEA Cost Engineering and Industrial Analysis Group. Sufficiency analyses are done using tools developed by our Future Force Formulation program at the Naval Surface Warfare Center Dahlgren Division (Rice 2006). The sufficiency analysis is conducted to the force architecture baseline developed by OPNAV.

Step 7: Check and iterate. If Steps 5 and 6 show that the alternative fleet is attractive in terms of acquisition cost and has sufficient capability, then it is a viable option. If not, then it is rejected and the synthesis/analysis loop is re-started.

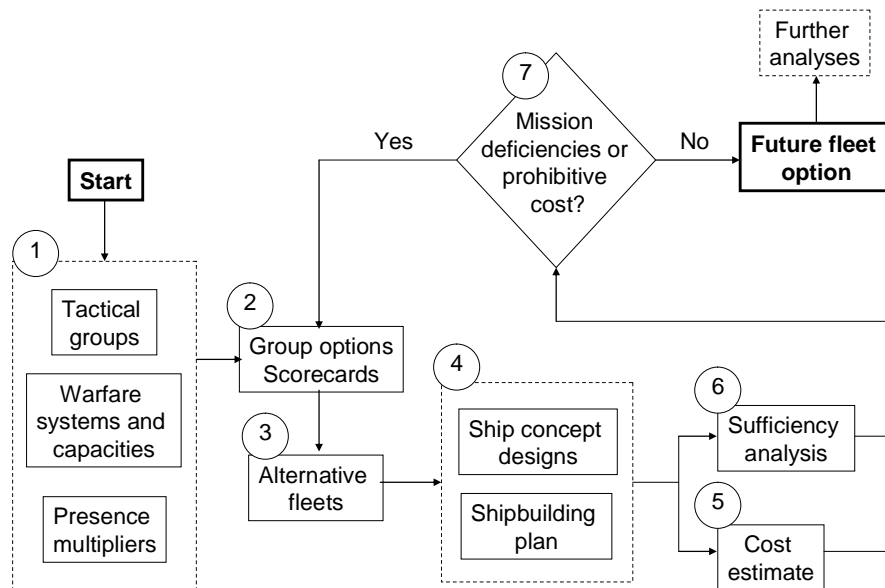


Fig. 1. Fleet synthesis and analysis workflow.

This method emphasizes (1) force structures populated by naval architecturally and programmatically valid concepts, (2) explicit checking of ship designs and force structures for peacetime presence and warfighting sufficiency, and (3) tracking of the retirement of older ships and their replacement with future concepts. The latter point is the focus of this paper. Time series tracking of the replacement of the Navy's planned future fleet with the alternative future fleet reveals the degree of force structure inertia that is in place under the study assumptions. Shorter life ships require more frequent recapitalization but they reduce force structure inertia as well as potentially creating other effects (Koenig et al 2008). Alternatively, the longer the ships last in the inventory, the longer the lead time required for new designs to dominate the force structure.

MULTIPLE VIEWS OF SHIP LIFE

Different measures can be used to describe the anticipated life or current age of a ship, depending on the analytical or planning issue at hand. Examples include expected service life, actual service life, operational service life, assessed age, design service life, and economic life. These are defined and discussed in this section.

Expected service life figures are force level planning numbers generated by the Office of the Chief of Naval Operations (OPNAV) to apprise other parties of how many years ships need to be kept in service to achieve a given force structure. Within a ship class, all ships have the same expected service life and that number is used to plan the SCN budget, OM&N budget, manpower needs, and other items within the Future Year Defense Plan (FYDP). It is also used to project future force structure beyond the FYDP as reported to Congress in the 30 year shipbuilding plan.

Actual service life is the time spent in commission, i.e. the chronological life of the ship from its initial commissioning to final decommissioning. Where appropriate, out-of-commission periods (e.g., while laid up in the reserve fleet or undergoing conversion) can be

subtracted. For this paper, our focus is post-World War II-designed surface combatants. None have been out of commission in reserve, so actual service life is an unambiguous measure.

Operational service life accounts for the differential rate of ship aging between operational years and years out of commission. It is approximated by time in commission (actual service life) plus time out of commission factored for a lower aging rate. As an example, consider the U.S.S. Chicago (CA 136, converted to CG 11). The ship was first commissioned in January 1945, taken out of commission in June 1947, recommissioned in May 1964, and finally decommissioned in March 1980. This ship's life span was 35 years, actual service life was 18 years, and operational service life would be estimated at 22 years using a factor of 0.25 for out-of-commissioned years.

Assessed age is a measure that has been discussed by the U.S. Navy's Board of Inspections and Surveys (INSURV). It would account for the material condition of the ship and its modernization status. Unlike commercial ships and Military Sealift Command ships, naval vessels are self-regulated from the maintenance management and execution standpoint. While this confers naval operational flexibility, it also means that material condition is an operational parameter to be assessed, tracked, and managed.

Design service life is the service life that the ship is designed to achieve. There was no service life invoked as a "design to" number in the Top Level Requirements of most existing U.S. naval vessels including the DDG 51 and FFG 7 classes. Furthermore, years-of-intended-service is not an input variable for most of the engineering calculations used to design a ship. Among the few features in a design that are directly linked to time-in-service is the provision for service life allowances (Sims 2007) and these can be tailored. For example, the CG 47 class was considered to be a post-mid-life upgrade version of the DD 963 so the designers aimed for half the usual service life reserves for

weight and vertical center of gravity (which was not achieved; the first ships were delivered heavy). The Navy has not conducted a comprehensive study of a ship design to determine the relationship between cost-to-design-and-build and years of intended service. This would require a series of parallel designs at the contract design level of effort to capture, at the system level, the changes to the design needed to impact the estimated service life. Existing programs with specific service life requirements (LPD 17 and T-AKE) have provided knowledge regarding how to achieve longer life from the hull, mechanical, and electrical standpoint. However, the Navy has not conducted any studies to remove those features and estimate the ship cost without them.

Economic life is an engineering economic estimate used by commercial shipowners for fleet planning. Merchant ships are capital assets; therefore, having taken a view on the future behavior of various global markets, their economic life can be calculated via cash flow analysis. The input information for this analysis includes the current market price of a new replacement ship (adjusted to reflect design and construction details), upcoming shipping market opportunities, projected changes in regulatory requirements, and technical and market factors involved in vessel operation, maintenance, and repair. Recently, merchant ship operations have produced strong earnings and new construction prices have risen sharply, thus prolonging vessel economic life. This can be observed in the average age of recycled ships which has risen from around 26-27 years in the 1990s to approx. 32 years as of last year (Mikelis 2007). Economic factors impact warships life as well, however the Navy has not defined a process for calculating the economic life of a naval ship.

SERVICE LIFE AND FORCE STRUCTURE

Service life has a direct impact on ship acquisition planning to maintain a given ship-count. Consider a fleet of 100 merchant vessels each having a life of 25 years. Four

new orders must be placed annually to maintain the fleet. When the price of new vessels rises then the new construction budget will have to increase correspondingly. Alternatively, if ships can be kept for 33 years rather than 25, then the 100-ship fleet needs only three new builds per year, a 25% reduction. A shipbuilding budget reduction does not necessarily follow; new construction pricing could rise enough to overbalance the effect of fewer orders. Furthermore, the average age of the fleet will increase, so maintenance, repair, and modernization budgets will eventually rise. All of these factors influence the shipowner's decision on whether or not service life extension is an attractive alternative to new construction.

The Navy has a requirement to maintain a 313-ship fleet over the next thirty years, and per-ship costs are rising. This puts the Navy in about the same situation as the hypothetical merchant shipowner above. Barring a shipbuilding price reduction, either the shipbuilding budget will increase, or the expected service life of existing and future ships will be extended, or some combination. This has been discussed for years on the occasion of each new release of the Navy's 30 year shipbuilding plan. For example, eight years ago it was calculated by one commentator that the force structure projected by the then-current 30 year shipbuilding plan was based on a 35-year "average expected service life of naval ships," which was asserted to be too long unless "huge investments were made to keep old ships operational well beyond their intended and historical service life." The recommended fix was a higher new construction budget (Brown 2000). In 2007, the assumption that ships would meet their expected service lives was noted as an item of concern: "...the Navy has no recent experience in keeping large surface combatants in commissioned service for 35 years" (Jean 2007, quoting Robert Work). "The Navy will add five years to the planned 35-year service lives of its workhorse Arleigh Burke-class destroyers, according to the latest version of the service's 30-year shipbuilding plan" and a Navy spokesperson was quoted

saying that “such a service life extension could...reduce pressure on the far-term shipbuilding budgets...” (Peterson 2008).

To date, expected service life has not been a robust predictor and this is shown in Table 1.

Considering classes introduced since World War II, the type average actual service life for cruisers has been 26.3 years. For destroyers, 25.4 years and for frigates, 19.8 years; well short of expected.

Table 1: Service lives of the 23 surface combatant classes introduced since WWII.

| Type | Class and number built | Shortest actual service life (years) | Longest actual service life (years) | Class average actual service life (years) | Type average actual service life (years) |
|------------------------------------------------------------------|-------------------------------------------|--------------------------------------|-------------------------------------|-------------------------------------------|------------------------------------------|
| Cruisers 8 classes, 54 ships (of which 22 active) | 1 x <i>Long Beach</i> | | 33.7 | 33.7 | 26.3 |
| | 9 x <i>Leahy</i> | 29.5 | 31.2 | 30.6 | |
| | 1 x <i>Bainbridge</i> | | 34.0 | 34.0 | |
| | 9 x <i>Belknap</i> | 26.8 | 30.3 | 27.8 | |
| | 1 x <i>Truxtun</i> | | 28.3 | 28.3 | |
| | 2 x <i>California</i> | 24.5 | 25.4 | 25.0 | |
| | 4 x <i>Virginia</i> | 15.9 | 19.0 | 17.7 | |
| | 5 x <i>Ticonderoga</i> (retired) | 18.3 | 21.7 | 19.8 | |
| | 22 x <i>Ticonderoga</i> (active) | 14.0 | 21.8 | 17.9 | n/a |
| Destroyers 8 classes, 143 ships (of which 52 active) | 1 x <i>Norfolk</i> | | 16.9 | 16.9 | 25.4 |
| | 4 x <i>Mitscher</i> | 15.2 | 25.1 | 20.0 | |
| | 18 x <i>Forrest Sherman</i> | 20.7 | 28.6 | 24.9 | |
| | 10 x <i>Farragut</i> | 28.1 | 32.8 | 30.6 | |
| | 23 x <i>Charles F. Adams</i> | 26.2 | 30.4 | 28.6 | |
| | 31 x <i>Spruance</i> | 18.3 | 29.5 | 23.6 | |
| | 4 x <i>Kidd</i> | 16.6 | 17.5 | 17.0 | |
| | 52 x <i>Arleigh Burke</i> (active) | 0.7 | 17.0 | 8.6 | n/a |
| Frigates 7 classes, 133 ships (of which 30 active) | 13 x <i>Dealey</i> | 14.7 | 18.9 | 16.4 | 19.8 |
| | 4 x <i>Claud Jones</i> | 13.8 | 15.9 | 14.7 | |
| | 2 x <i>Bronstein</i> | 27.2 | 27.5 | 27.3 | |
| | 11 x <i>Garcia</i> (Incl. <i>Glover</i>) | 20.0 | 24.6 | 22.4 | |
| | 6 x <i>Brooke</i> | 20.4 | 22.5 | 21.3 | |
| | 46 x <i>Knox</i> | 17.4 | 23.2 | 21.2 | |
| | 21 x <i>O.H. Perry</i> (retired) | 13.9 | 22.5 | 17.4 | |
| | 30 x <i>O.H. Perry</i> (active) | 18.9 | 28.6 | 24.0 | n/a |

Note: Active is as of mid-2008. Sources: McCarton 2005, 2006.

Three sets of service life assumptions

As pointed out by Labs (2003), the crux of the U.S. Navy's force structure issue is surface combatant service life; that is where the large force structure impact is found and our analysis concentrated there. A spreadsheet was built to track ship lives from the mid-1990s through 2038; i.e. the recent past plus the current 30 year shipbuilding plan. The 30 year shipbuilding plan, as mentioned before, is based on expected service life figures. The results are shown in Fig. 2.

The middle curve plots the historical force structure levels through 2008 plus the projected 30 year plan. It is the "historical past + projected expected service life" case. For example, the CG 47 is shown as decommissioning at age 22, in 2004. In 2008, the total surface combatant force is 106 ships.

The upper curve is the all-expected service life case. This is a hind cast, or "what would have been" case, to see where we would be today if past expected service lives had been realized. Here, the ships that appear during the period 1995-2038 are retired at expected service life. For example, compared to the base case, the CG 47 gets 13 extra years of life and is decommissioned at age 35 in 2017; the FFG 7s are kept for 30 years, and so on. In 2008, the total surface combatant force is 166 ships. Therefore, had expected service life been achieved from 1995 out, the U.S. Navy of 2008 would have 57% more surface combatants. Compared to the middle curve, the impact of the all-expected service life assumption falls off in future years as the force structure becomes dominated by future ships, which (in planning process) meet their expected service life.

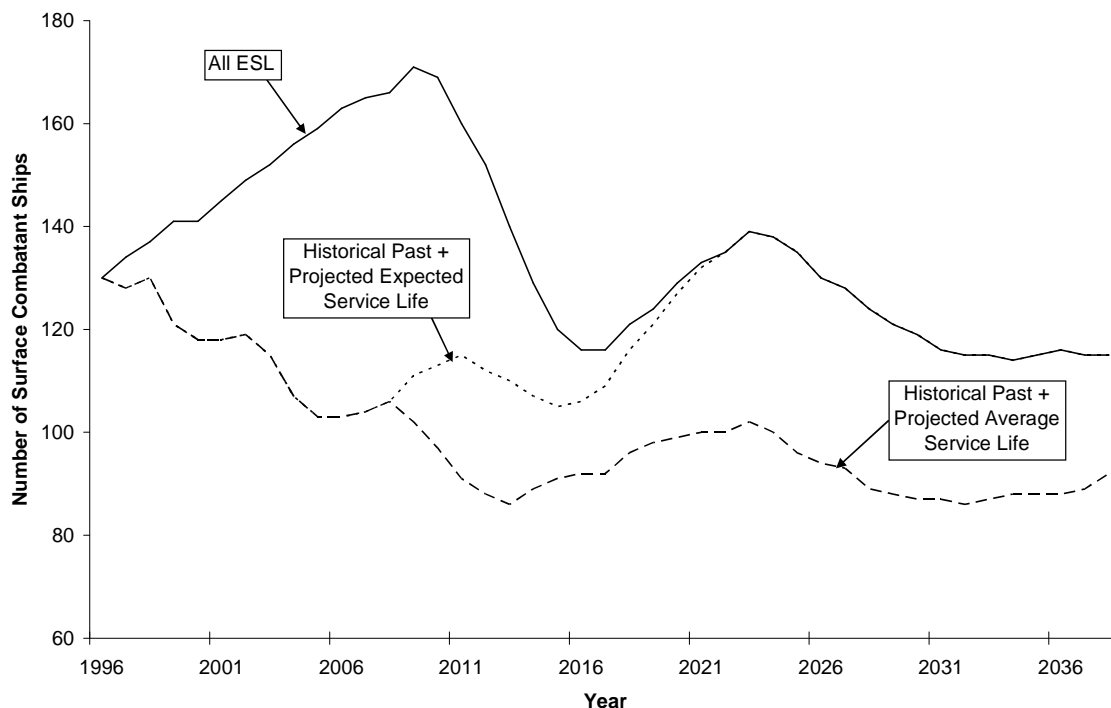


Fig. 2: Projected surface combatant force structure under three sets of service life assumptions

The lower curve shows the historical force structure levels through 2008, with average service life (from Table 1) applied to the Navy's post-2008 projected force structure (30 year plan). It is the "historical past + projected average" case. This is a forecast case, to see what will happen if surface combatant lives are those suggested by historical actuals rather than expected service lives. As the base case already incorporates historical information, this curve tracks the base case during past years and begins to diverge as soon as future retirements begin. For example, the service life of the DDG 51 class ships on this curve is 26 years rather than the expected service life which is 35.

ELEMENTS INFLUENCING ACTUAL SERVICE LIFE

Why do the actual service lives of surface combatants so often fall short of expectations? There are numerous factors that influence naval ship service life including world events that impact the national security posture, technical obsolescence, maintenance issues, and industrial base considerations. The remainder of our discussion here is strictly limited to technical obsolescence and maintenance.

Technical obsolescence is a key driver of service life for surface combatants due to their highly integrated warfare systems. This makes surface combatant modernization a priority. One naval authority has been quoted observing that the Navy decommissioned the *Spruance* and *Kidd* class destroyers and the first five *Ticonderoga* class cruisers (see Table 1) because of how difficult it would have been to modernize them, for cost reasons (Jean 2007). Modularity and open systems architectures are two approaches to building in the potential to realize more economical and timely future modernizations. Non-modular invasive surgery has also been used for this purpose, as in the extensive FRAM (Fleet Rehabilitation and Modernization) program of the late 1950s-1960s.

Maintenance can make or break a ship's service life. Carefully maintained vessels can serve out their entire expected service lives and more. But inadequate maintenance during the early and middle ranges of a ship's life can make life extension prohibitively expensive and this, in the absence of other overriding factors, would prompt a decision to retire early. For Military Sealift Command ships and commercial ships, regulations and standards covering maintenance and repair are enforced by outside entities, i.e. the U.S. Coast Guard and the classification society. The Navy, however, being largely self-regulated, is subject to no such outside checks and compliance with the result that maintenance can be (and often is) deferred. Service life extension on a ship that has had extensive maintenance deferral will incur a substantial maintenance catch-up cost along with the corresponding additional in-yard time. A general, long-term movement to longer service life implies that vessel maintenance will assume greater relative importance and will incur increased cost.

CONCLUSIONS

In the realm of long-term naval force structure planning, uncertainty dominates. Planners build on shifting sands and "...there is some truth in the complaint that work on long-term defence planning comprises a series of short-term crises" (Pugh 1986:99). Uncertainties faced by U.S. Navy force structure planners and naval architects include unpredictable global political and economic changes, threat developments, technology readiness of future systems, and the ability of the U.S. economy to support required force structure investments.

Ship service life is a high-impact variable. Changes to expected service life can be very useful for planning purposes. For example, an extension has the effect of bolstering projected long term force levels without incurring an immediate additional cost. However, if an extension is granted, then follow-up analysis is required to provide budgeting for implied increased funding in

operations and support, maintenance, and modernization. Because of this impact, we recommend that service life adjustments reflect a balanced analysis. This includes future ship and force structure concepts that are backed by naval architecturally sound designs, projected in a rigorous manner to show the way forward.

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